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A Review on Analysis of Thermal Contact Resistance across Aluminium Interface using FEA Method

Barkade N. M.[1], Sadhwani S. V.[2], Kalyankar R. A[3]
[1]Research Student, [2]Principal, [3]Assi.Professor, Dept. of Mechanical Engg, LNBCIET, Raigaon, Satara, Affiliated to DBATU University, Lonere (MH), India.

***Abstract:** An experimental setup to measure the thermal contact resistance across aluminium assemblage is described and from that, the results obtained are presented. A distinctive experimental set-up was fabricated to carry out axial heat flow steady state experiments for the estimation of thermal contact resistance at the assemblage of two materials. Two different materials (Aluminium and Copper) are selected for the experiments considering their mechanical and thermal properties. A precise estimation of thermal contact resistance for the interface of sets of similar materials was one of the most important results of this research. The effects of the material properties, surface roughness and the load conditions (nominal interface pressure) have been studied and acknowledged. in addition, the experimental results are compared with theoretical models, showing their limitations to make a precise estimation of the thermal contact resistance in the range of the used parameters. The resulting thermal contact resistance data results are used in various applications of heat transfer. So many factors influence the heat transfer across solid interface. These contain the material properties, flatness and roughness of the contacting surfaces, interface pressure, temperature and interstitial material if any. Results presented show the deviation of thermal contact conductance as a function applied interface pressure for aluminium. As expected, the increase in interface pressure, decreases thermal contact resistance, except in case of the eutectic, in which it was nearly constant. The softer the interstitial material then, the lower the thermal contact resistance.*
***Keywords:** Thermal contact resistance (TCR), Heat transfer rate, Heat generated, Pinching effect, Thermal conductivity.*

I. INTRODUCTION

The issue of Thermal Contact Resistance across two different metallic materials shows, when heat flows through two different metallic bodies placed in contact, there is a microscopic temperature discontinuity at the interface. This temperature discontinuity results from thermal contact resistance. This thermal contact conductance at the metal interface can be improved by increasing actual contact area. This can be done by one or more of the following:
(i) Applying high pressure at assemblage. (ii) By making aluminium contact surface very smooth and flat. (iii) Using soft interstitial material (soft metal such as Indium, liquid or variety of conductive greases). Another problem is a potentially great influence of finite Thermal Contact Resistances (TCR) between the sample and other element of the measurement system. This trouble is particularly significant if air is present on the contact surfaces are rough and filled with air. When random rough surfaces are positioned in mechanical contact, then the real contact occurs at the summit of surface asperities which are called microcontacts. Thermal contact resistance (TCR) of in compliance rough surfaces in a vacuum is proportional to the real contact area. When two surfaces are bring into contact, the actual contacting area between the two surfaces is actually only a small part of the total apparent contact surface area and is generally between one and ten percent. Macroscopic contacts are directly dependent on the flatness or waviness of the surfaces in contact and also the degree of surface roughness. A resistance to heat flow produced by this restriction of heat flux lines through these small contacts and the temperature discontinuity results since in effect the heat flow is "delayed" from crossing the interface. This resistance to heat transfer across the interface is defined by,

$R = (A)(\Delta T)/Q$

Where, R = thermal contact resistance,
A = apparent contact surface area,
ΔT = temperature drop across the interface,
Q= heat flow rate across the interface

The thermal contact resistance is a function of the temperature level and the apparent contact interface pressure or load ever since at higher interfacial pressures elastic and plastic deformation will occur creating greater solid-to-solid contact area. A single perfect contact over part of the apparent contact area is usually considered by analytical approach to the problem of thermal contact resistance.

II. LITERATURE REVIEW

A.M. Khounsary, D. Chojnowski, and L. Assoufid [1] focused on the parameter which considered Thermal resistance in practical terms or its inverse, the conductance depends on (i) material hardness, (ii) roughness and flatness of the surfaces, (iii) interstitial material, if any, (iv) applied interface force, (v) thermal conditions, and (vi) other less significant factors. Thermal contact conductance at the Si-Cu interface can be improved by increasing the actual contact area.

T.McWaid, T.E.Marschall [2] discussed the method of determining thermal contact resistance of wavy surface. For finding the thermal contact resistance of real contacts, a new method has been presented. In this system, assuming a regular sinusoidal surface profile, the real contact area in terms of applied forces has been observed and thermal contact resistance calculated.

Ju liu [3**]** they focused on the solid materials which is used in electronic industries. The thermal contact resistance study on two brass columns was conducted in different conditions, which were classified as four major aspects, including the interfacial pressure, the voltage of heater, thermal conductive adhesive and environmental temperature compensation. By the experimentation the thermal contact resistance measured with thermal conductive adhesive at the interface is lower than that the one without thermal conductive adhesive.

MajidBahrami, M. Michael Yovanovich, J. Richard Culham [4] studied on random rough surfaces are when placed in mechanical contact, real contact occurs at the summit of surface asperities which are called microcontacts. The real contact area Ar, the summing of the microcontacts, forms a little portion of the small contact area; typically a few percent of the nominal contact area. To study the restriction resistance microcontacts, in the experimentation the joint is usually studied in a vacuum where the heat transfer between contacting bodies occurs only via conduction through microcontacts. They proposed correlations for maximum asperities heights as functions of surface roughness.

Nenad stepanac, nenad Milosevic [5] studied on guarded hot plate method which is a standard method for the measurements of thermal conductivity of solids in the range from 0.1 to 10 W/mK. It is used for materials such as ceramics, materials of biological origin, polymers and other. The method can be applied in a broad working temperature range, from 80 K to 1200 K. The most important principle of the method is one-dimensional steady-state heat conduction through a sample under test. This method has vast influence of finite TCR between the sample and other elements of the measurement system.

Zhe Zhao et al [6] discussed on investigation of whether pressure and temperature can affect thermal contact resistance, have proposed a new experimental approach for measurement of the thermal contact resistance. By taking the TCR between carbon-carbon composites and phenolic resin, cuprum and aluminium as the examples, the influence of the thermal contact resistance between specimens under pressure struggling is tested by experiment.

M.H. Shojaefard and K. Goudarzi [7] studied on numerical estimation of thermal contact resistance at contacting surface. For various manufacturing processes, the heat transfer between the components, the tools and the environment has an effect on tool-life and the accuracy of the formed component. A new transient method and measurement apparatus are used in which the measurements are conducted on specimens, which are retained under pressure.

Xiaobing Luo, Han Feng, Jv Liu, Ming Lu Lio and Sheng Liu [8] searched a new method to determine thermal contact resistance. The contact resistance was frequently applied in quality testing of relays, switches, PCB pads and testing of the shield assembly for EMC. The method of measuring contact resistance has been summed up in this article and the factors that bring measurement uncertainty have been discussed.

III.GAP IDENTIFICATION

The factors which determine the real contact area between contiguous solids can be divided into two areas of importance: surface geometry (roughness, waviness) and surface interaction (plasticity, elasticity, hardness). For example, the size of the actual contact area, which depends on the geometrical properties of the contacting surfaces, determines the actual pressure acting on the asperities, while the roughness determines the asperity density over the contacting area.

The present knowledge of surface interactions does not allow one to use either the classical elasticity or plasticity theory unless the compressed surfaces are of regular geometrical form with either completely elastic properties or for the case of plasticity without roughness. The most important physical (mechanical) properties are the modulus of elasticity, the hardness or yield pressure of the asperities, and the plasticity in the determination of the following: (i) real contact pressure; (ii) the displacement or approach of the surfaces as a result of the deformation of the surfaces under compression; and (iii) the actual area of contact (number and size of contact spots).

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IV. OBJECTIVE

A. Prime objectives of the proposed investigations are to study the concept of the thermal contact resistance (TCR) and parameter involved in the measurement such as temperature across the test specimen, wattage provided to the heating side of test specimen, heat carried away by cooling side of test specimen.

B. Study of the factor affecting on the TCR by keeping the other parameter constant which involved the relation between TCR and surface roughness of specimen. Study of the relation of the factor affecting on TCR & heat transfer rate by the graphical method involves graph of heat transfer rate and TCR for the different test specimen having different surface roughness. This method also studies the same concept by using different thermal interface materials between test specimen.

C. One of important objectives of this methodology for the experimental set up is to find out remedies to reduce thermal contact resistance so as we can increase heat transfer rate effectively for the industrial applications.

V. EXPERIMENTS

A. Specification of Experimental Setup

Plate 1: Ø150×8mm thick
Plate 2: Ø150×8mm thick
Heater: 200 watt (Ø100 ×2mm)
Ammeter: 1-5 amps AC
Voltmeter: 0-500 volt AC
Heating plate (Copper plate): Ø150 ×20mm thick
Cooling plate (Aluminium plate): Ø150 ×20mm thick
Thermocouple (K type): bulb (0-400) ^{0}C
Temperature indicator: 4 channel (0-400)^{0}C, K type thermocouple input of 0-20mA

B. Experimental Setup

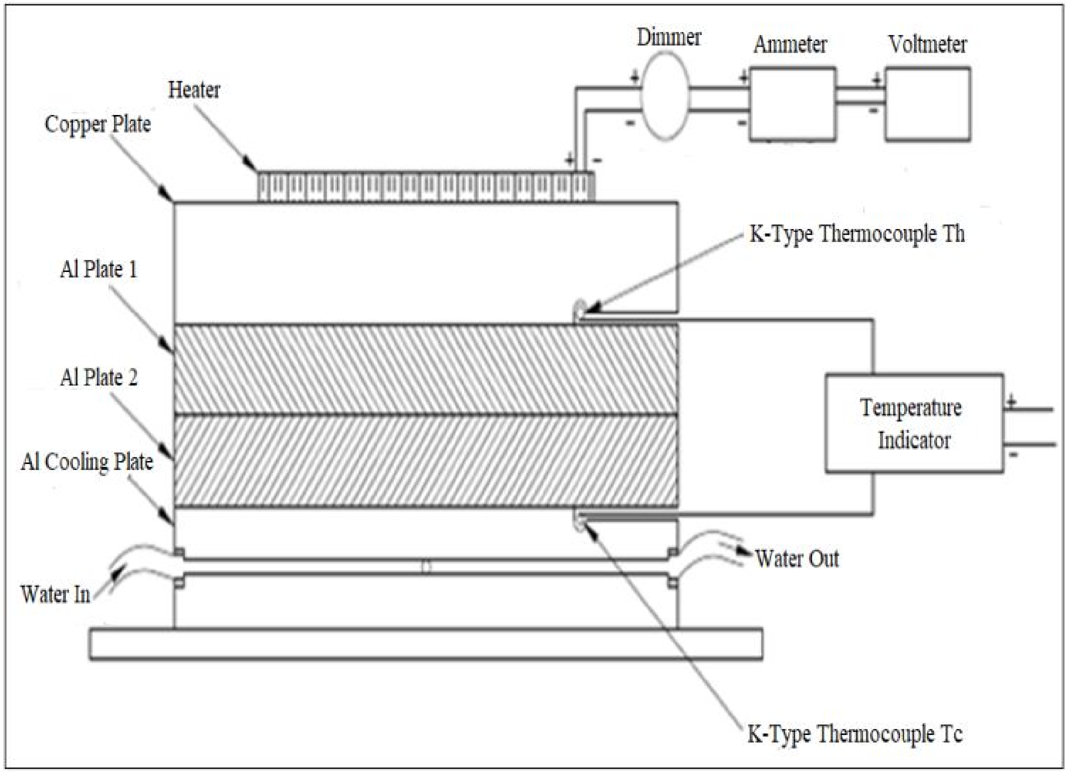

Fig-1. Block diagram of experimental setup

Experimental set up consist the arrangement of the specimen between the heating and cooling side so there are the constant heat flow from the heating to cooling side. The two test specimen are mounted on each other and by arranging the bolting arrangement, pressure is applied on it so the contact between the plates should be air tight. On the heating plate transferring the heat to the test specimen is of the copper. The heater made of the MICA is fixed on the one side and wattage provided to the heater is measured by the voltmeter and ammeter and control of the heat energy provided is by using the dimmer. On the other side of set up there is cooling arrangement foe the rejection of the heat flowing through the test specimen. These cooling arrangement plates are made of aluminium for better cooling. For the fast cooling process water cooling arrangement is done in the plate with the water inlet and outlet arrangement. This whole setup is mounted on the table which is made of the CI square pipe so it gives the rigid support to the experiment. On the one side of this stand support vertical control panel is provided so the parameter required to measure can be seen and also parameter wants to be controlled can be controlled by the switches and meter also mounted on the control panel. This control panel is consisting of temperature indicator for the indication of the temperature across the plate. Ammeter and voltmeter is provided on the panel so it indicates the energy provided to the heater. Dimmer is also mounted on the panel which will control the current provided to the heater.

VI. OBSERVATION & CALCULATION

A. *Observation Table*

Surface roughness is measured by using the surface roughness measuring instrument, these value are for 25mm length and this instrument create the values depending the average of deep and cruest present in the 25mm measured surface. The different temperature reading taken from test setup. See the following different temperature reading at Surface finish between Al plate-

Table-1. Temperature reading at Surface finish between Al plate Ra=0.625

Sr. No.	Temperature at Hot side Th (in ^{0}C)	Temperature at Cold side Tc (in ^{0}C)	I X V (in Watts)
1	47	38	37.69
2	48	40	33.5
3	49	42	29.31
4	50	42	33.5

Table-2. Temperature reading at Surface finish between Al plate Ra=0.125

Sr. No.	Temperature at Hot side Th (in ^{0}C)	Temperature at Cold side Tc (in ^{0}C)	I X V (in Watts)
1	47	34	54.44
2	48	34	58.63
3	49	33	67
4	50	30	83.76

Table-3. Temperature reading at Surface finish between Al plate Ra=0.00

Sr. No.	Temperature at Hot side Th (in ^{0}C)	Temperature at Cold side Tc (in ^{0}C)	I X V (in Watts)
1	47	20	113.07
2	48	20	117.26
3	49	23	108.88
4	50	23	113.07

B. *Calculation Part:-*

1) Surface Area = $(\pi r^2)/4 = 3.14 \times 0.15^2 = 0.07068$

2) Heat Generated

Qgen= A amp x V volts

3) Heat transfer from cold to hot section

Q= kA (Th –Tc)/L

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a) Heat Transfer Rate at Ra=0.625

=0.237x 0.01767(47-38)/0.0015=25.13w/m²

i) Calculation for TCR= (Temp Diff x Ra Value) / Heat Transfer Rate

= (47-38) x 0.625/25.13 =0.2238

b) Heat Transfer Rate at Ra=0.125

=0.237x 0.01767(47-34)/0.0015=36.29w/m²

i) Calculation for TCR= (Temp Diff x Ra Value) / Heat Transfer Rate

= (47-34) x 0.125/36.29 =0.0448

c) Heat Transfer Rate at fluidic media, Ra=0.00

=0.237x 0.01767(47-20)/0.0015=75.38w/m²

i) Calculation for TCR= (Temp Diff x Ra Value) / Heat Transfer Rate

= (47-20) x 0.00/75.38 =0.00

VII. MODELING AND ANALYSIS

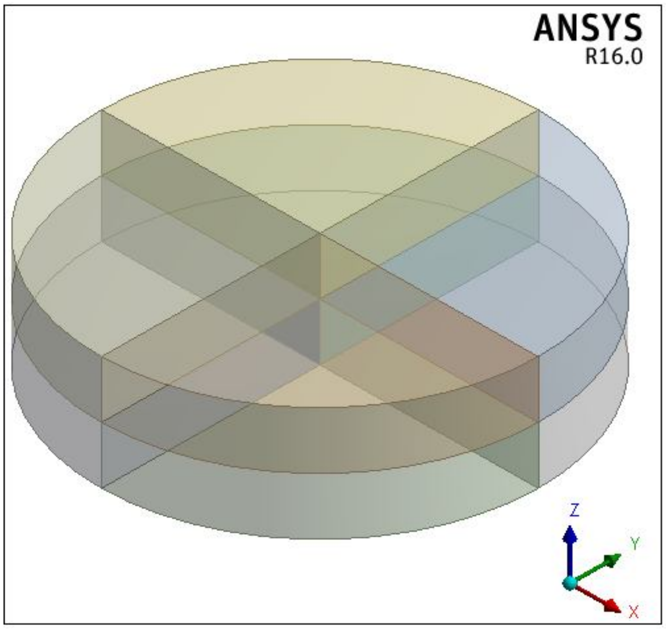

Fig-2. Geometric Model of Aluminium plates.

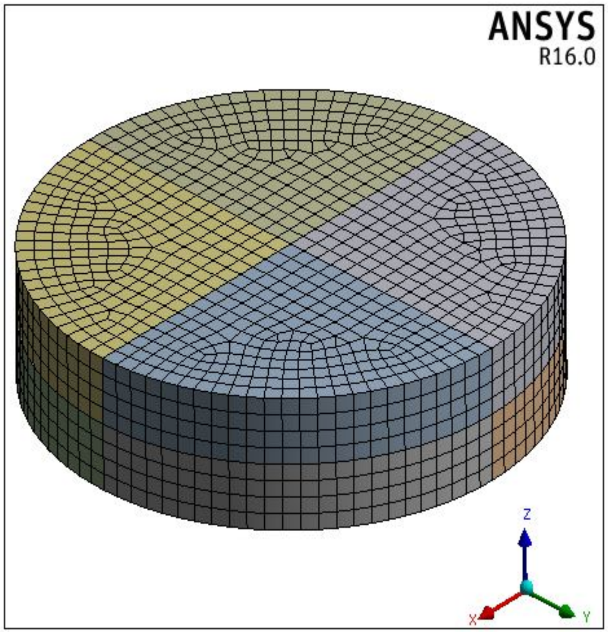

Fig-3. Meshing Geometry

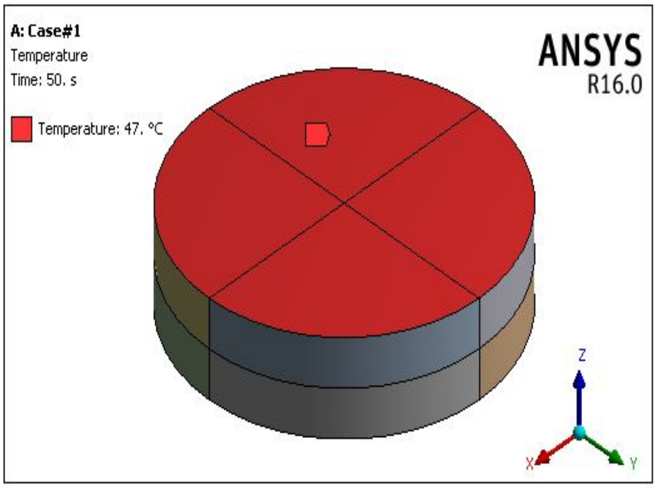

Fig-4. Boundary condition at temperature 47^{0}C

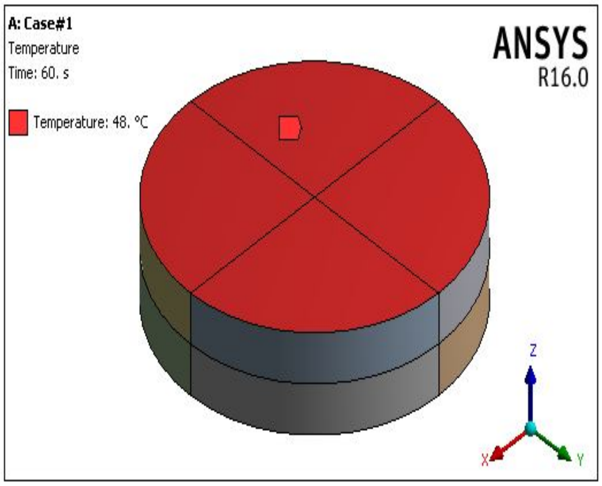

Fig-5. Boundary condition at temperature 48^{0}C

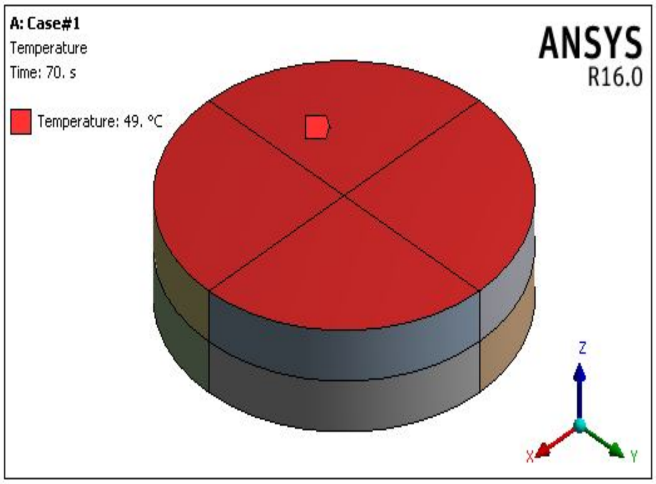

Fig-6. Boundary condition at temperature 49^{0}C

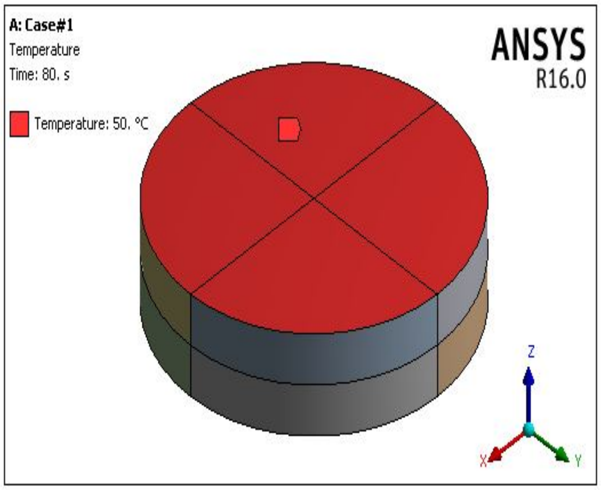

Fig-7. Boundary condition at temperature 50^{0}C

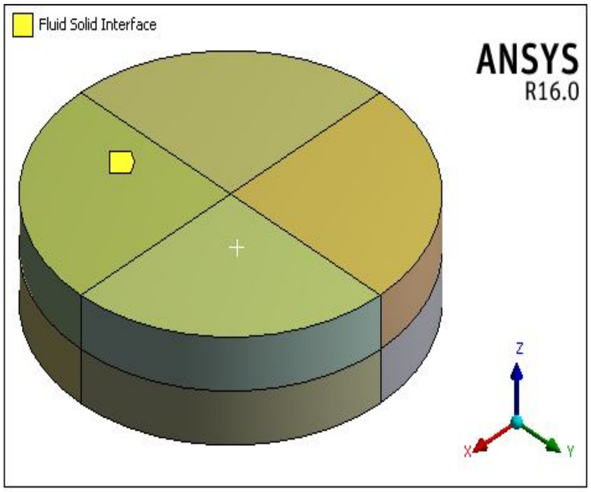

Fig-8. Boundary condition for Cooling Plate

VIII. RESULT & DISCUSSION

Table-4. Result Summary of Experimental parameter reading

Sr. No.	Temperature at Hot side Th (in ^{0}C)	Ra Value	Heat Generated i.e. I X V (in Watts)	Heat Transfer Rate (in w/m²)	Thermal Contact Resistance
1	47	0.625	37.69	25.13	0.2238
2	47	0.125	54.44	36.29	0.0448
3	47	0.00	113.07	75.38	0.00

Discussion on Results:-

A. *Effect of Surface Roughness*

Heat Transfer and roughness of surface are directly affected each other and relation between them involves the term thermal contact resistance. At Ra value 0.625 heat transfer rate is 25.13 w/m², at Ra value 0.125 heat transfer rate is 36.29 w/m² and at Ra value 0.00 heat transfer rate is 75.38 w/m². Contacting face between two similar or dissimilar material may largely affect the rate of heat transfer as the high roughness provide more space in between the plate, so it is found that high roughness gives low rate of heat transfer.

B. Effect of heat Transfer Rate

As heat transfer rate is increases, thermal contact resistance decreases. For first test, heat transfer rate is 25.13 w/m² and thermal contact resistance is 0.2238. For second test, heat transfer rate is 36.29 w/m² and thermal contact resistance is 0.0448. For third test, heat transfer rate is 75.38 w/m² and thermal contact resistance is 0.00.

C. Effect of Thermal Contact Resistance

As surface roughness increases, thermal contact resistance also increases.

D. Effect on Heat Loss

As the surface roughness increases the heat loss rate is also reduced. Contacting surface of any two similar/dissimilar material plate are very largely affect the heat loss quantity. Low contact resistance may lead to minimize heat loss.

E. Remedies For Maximum Heat Transfer & Minimum Heat Loss

As third reading shows that, putting the fluidic i.e. heat transfer rate through involving the fluid is maximum media reduce the surface roughness and hence increase transfer rate. Providing the good surface or inserting additives like fluidic media can minimize the resistance for heat flow. Whole study shows that, in any energy heat equipments involved in surface contact heat transfer affected majorly due thermal contact resistance that are difficult to calculate.

IX. CONCLUSIONS

From the present work, the conducted experimental study concluded following points.

A. Surface roughness of aluminium plates is most significance influences on thermal contact resistance and heat transfer rate.
B. Thermal contact resistance mostly doesn't change with the increase of input voltage of heater and the thermal contact resistance in the experiment with temperature compensation is lower than that the one without temperature compensation.
C. Thermal contact resistance in the experiment with thermal conductive adhesive at the interface is lower than that the one without thermal conductive adhesive.

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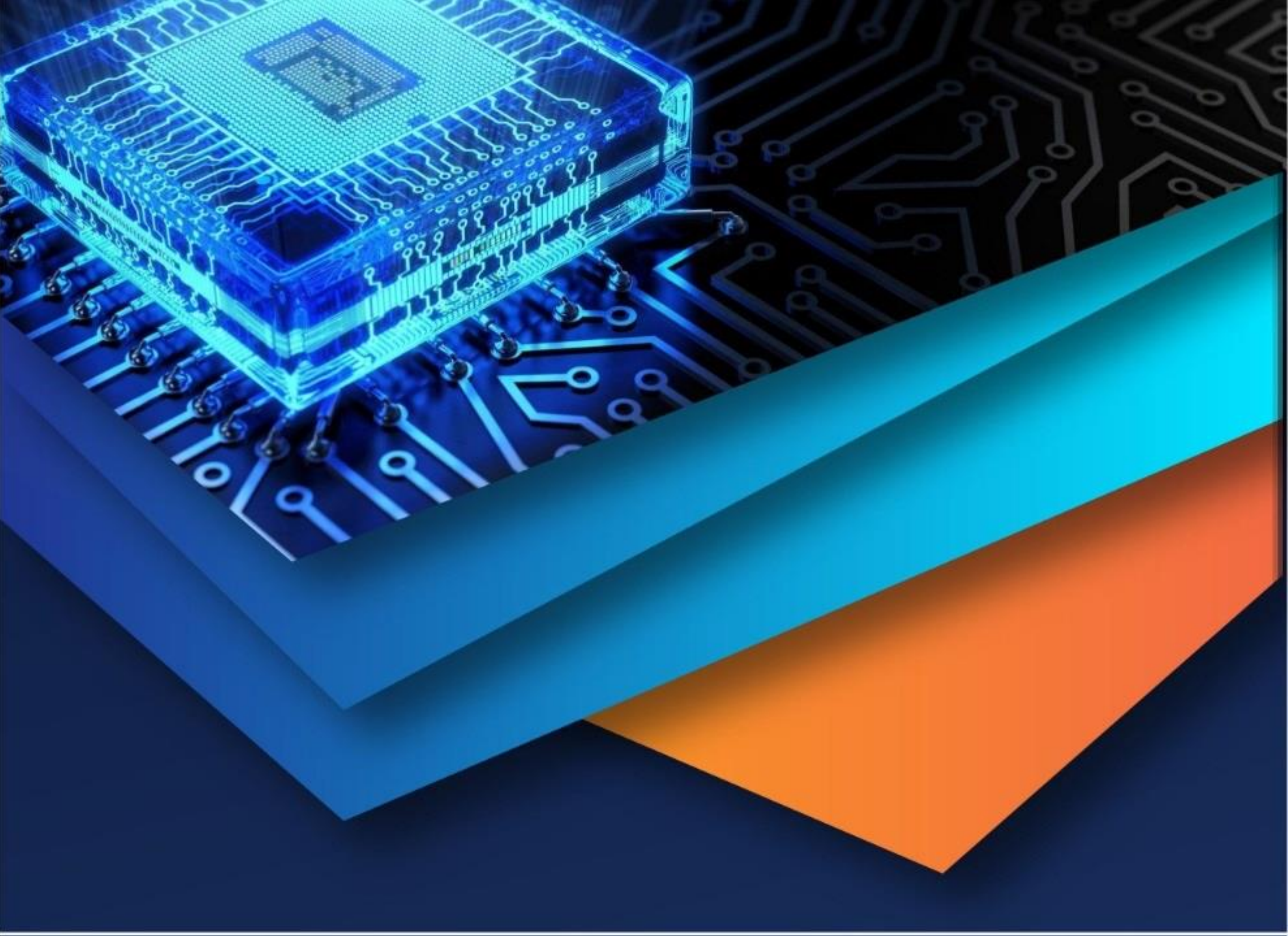

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